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COLOR PERCEPTION.

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That most of the theories of color perception extant are, in the light of present scientific knowledge, illogical and absurd is quite evident to even the casual observer.

In order to arrive at a fair and intelligent conclusion it is necessary that the main principles of the more important theories should be analyzed and compared.

The first scientific theory of light was brought forward by Sir Isaac Newton, in 1668, and is called the corpuscular theory. This, I presume, is familiar to all of us. The theory of color perception advanced by Newton and his followers is simple, and if the main hypothesis were correct would be entirely satisfactory. It is condensed in the following paragraph from a book published in 1759 by that distinguished physiologist, Dr. Wm. Potterfield, of Edinburgh:

"§ 5. The third manner in which colors may be considered is the passion of our organ of sight, that is, the motions or vibrations excited in the fibres of the retina by the impulse

or stroke received from the rays of light; which motions or vibrations being propagated along the solid fibres of the optic nerves into the brain, cause the sensation of colors. For the rays of light being corpuscles of different magnitudes, will, by striking the retina, excite vibrations of different bignesses, which, according to their bignesses, must excite sensations of several colors much after the manner of the vibrations of air, according to their several bignesses excite sensations of several sounds; and particularly the shortest or most refrangible rays will excite the shortest and weakest vibrations for making a sensation of deep violet, the largest or least refrangible, the largest and strongest vibrations for making the sensation of deep red, and the several intermediate sorts of rays, vibrations of several intermediate bignesses to make sensations of the several intermediate prismatic colors; but when the several heterogeneal rays are blended together promiscuously, they must, then, in falling upon the *retina*, excite several other different sorts of vibrations for making the sensations of the several cempound colors, which will, therefore, differ among themselves according as the light is composed of more or fewer of the different colored rays, or as they are mixed in various proportions."

The corpuscular theory of light has been disproved in many ways. The undulatory theory, now generally held, originated with Huyghens in 1678. All theories of color perception to be acceptable must rest upon his theory until that is disproved. The one most generally accepted was that evolved by Thos. Young in 1802. Helmholtz has ably seconded this in our generation. Backed by these great names the world has tacitly accepted their opinion as the ultimatum.

Observers have imagined, from the complexity of the retinal mechanism, tnat each layer must have a special perception of its own. Some have even gone so far as to name these characteristics. They overlook the fact that the eye is simply an optical instrument, each part being essential to the function of every other, and perfect action being impossible without existence of all the structures.

It does not matter for any theory which is called the percipient layer, provided that each elementary portion of the retina is connected with the brain centres by one or more nerve fibres. Thos. Young advocates three of these elementary portions adapted to the reception of three sensations of color, which he considered to be primary. One set of sensations, strongly acted upon by the waves of light due to long intervals, producing a sensation we call red, another set responding most powerfully to those of medium length, generating green, and a third most strongly stimulated by short rays, producing the impression of violet. The red of the spectrum acts most powerfully on the first set, and according to Young, acts also upon the other two sets of nerves, but with less energy. [This is better understood by inspection of the accompanying diagram taken from the Physiological Optics of Helmholtz.]

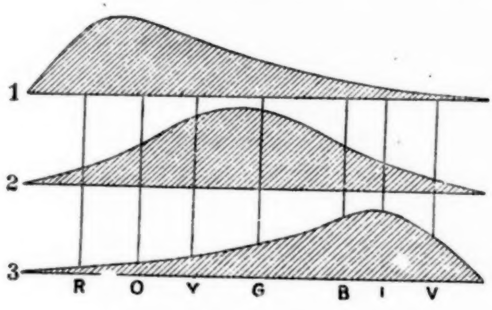

FIG. 2.

Here are placed the colors of the spectrum in order, the curves indicating the degree to which the three kinds of nerves are acted upon. We see that the nerves of the first kind are most powerfully stimulated by red light, less by yellow, and very little by violet. The next point in his theory is that when these three sets of nerves are stimulated in the same degree the sensation we call white is produced.

In 1878, Prof. Hering, of Prague (without any special endeavor to disprove the theory of Young), brought forward a proposition, which we think has less to recommend it than the

previous one. In Hering's theory we have three peculiar substances which are chemical, and not anatomical. They are designated as the white-black, the red-green and the blue-yellow. He conjectures that these substances are affected by light in a peculiar manner. The red-green substance is acted upon by no color but red and green, and these act in opposite ways. Red light, for example, acts in a decomposing or disassimilating manner ("D") and produces a sensation of red.

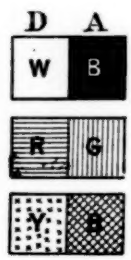

Fig. 3.

Green light acts in a regenerating or assimilating manner ("A") causing green. Blue has an "A" action on the blue-yellow substance; yellow a "D" action (Fig. 3). He recognizes four fundamental colors instead of three, which are paired, the components of each being antagonistic. For where the "A" and "D" actions in any substance are equal, the effect is neutral—no sensation resulting. On the third substance, the black-white, white light acts in a "D" manner, while black has an "A" action. Moreover, both the other substances are affected in an "A" and "D" manner by white and black.

On December 19, 1880, a paper was read before this society, the author advancing a theory, original with him, of color perception, and endeavoring to disprove the views originally accepted. The author of this article is Dr. Swan M. Burnett, of this city. Much has since been published concerning this subject by Burnett and others, and his work has been reviewed

and criticised both in this country and in Europe, the late Giraud Teulon, of Paris, giving considerable prominence to his views in the attacks he made upon Donders' defense of the Young-Helmholtz theory. A paper embodying Burnett's views in considerable detail was published in the *American Journal of Med. Sciences* in July, 1884. Although the scientific minds of America have eagerly seized this theory as a solution of color perception, yet in Europe it has received but little support, the majority of scientists in that country preferring to rest under the shadow of Helmholtz.

In 1885, Dr. Chas. Oliver, of Philadelphia, published the results of his deductions and experiments, which he called "A Correlation Theory of Color Perception." His work displays much ingenuity, and though veiled by a mass of extraneous matter, tends to the same end as Dr. Burnett's.

Dr. L. Webster Fox and Mr. Geo. Gould in 1886 brought forward a brochure on "Heat Considered as the Retinal Intermediate of Light and Color Sensation," the main principle of which, they acknowledge, was set forth in Burnett's paper.

Deductions made from these seem to represent the subject in the following theorems:

1. *a.* The retina is simply a receiving and transmitting structure which gives up faithfully to the optic nerve the impressions made by the waves of luminiferous ether.

1. *b.* The retina is an organ, whose ultimate structure is such as to allow it to respond at one and the same time to a large number of ethereal vibrations, at least such a number as shall be represented by the clearly distinguishable colors of the spectrum.

2. *a.* These vibrations may be carried along the same nerve at one and the same time.

2. *b.* These vibrations are transmitted to the central terminus of the filament in the brain where they are fully evolved, making a change in some unknown contiguous perceptive elements which are presided over by the sensorium. They are here, by the quality and nature of the change produced, differentiated into various perceptions.

3. There are no anatomical, chemical or physical grounds for either the theory of Young or Hering.

Oliver tries to step beyond that gulf, over which the mind of man cannot pass, and attempts to explain the manner in which the impressions are appreciated. He involves his theory, and greatly lessens the value of his deductions, by endeavoring to prove the existence of an "energy equivalent" resident in the nerve tip and which, when excited, is carried almost instantaneously to the brain. Although on some points these authors differ, it matters not for the main principle so long as it is declared that perception and differentiation reside in the brain, and not in the retina. It does not seem probable that the wave motion of ether undergoes a certain change in the retinal and nerve tissue, influencing the "nervous conductibility" (*i. e.*, the mode of molecular vibration). It is believed that each impression is conveyed to the brain cells separately and distinctly. Prof. Burnett, as we see, goes back to the original views of Newton, simply adapting the undulatory theory to his hypothesis. Instead of the retina being affected by the "nature and bigness" of the light corpuscles, he conceives it to be affected by the varying number and wave lengths of the ethereal undulations.

Which of these theories shall we accept? Which is more nearly in accordance with the observed facts of present scientific knowledge in the domain of wave motion and molecular physics? We must carefully lay aside all prejudices or we may be deluded by highly colored statements into accepting that which, if looked at in the proper light, would be untenable. The Newtonian theory of light is out of the question, as it has proved to be false in many ways. Now, as we have accepted the undulatory theory, it behooves us that our deductions shall conform to those brought forward by Huyghens and his illustrious followers. But Young, Hering and the rest of them also accept the undulatory theory, therefore we must first dispose of those which conflict with nature's known laws, before any other theory is admissible. Take the Young-Helmholtz theory:

At the first step we stumble upon a great stone. Young and Helmholtz (and also Hering) make the retina not only a receiving and transmitting apparatus, but a differentiating one as well. If they believe that the brain differentiates all other impressions why should they make a special exception as regards color, and suppose that for the appreciation of this a certain part of the eye is set aside as a discriminating organ? Now, they overlook a well known physical fact: When bodies are heated the ultimate molecules of which they are composed are in a state of vibration, and if heated to the point of luminosity this vibration communicated to ether culminates with us in the sensation of light.

Burnett says: "It must be accepted as a fact, therefore, that all the vibrations found in the ether must have had their existence primarily in the molecules of the luminous body. When a body is brought to a white heat, for example, the molecules of which it is composed must make all those phases of vibrations which correspond to every color into which white light may be decomposed, and must make them at one and the same time. In no other way is it possible to explain satisfactorily and consistently the various vibrations of the ether and the manner in which they are brought about.

Now, Young must have known this, for he could hardly have supposed that there were three separate and distinct fibres in all luminous bodies giving out white light, particularly in those bodies which, so far as it is possible to ascertain, are strictly homogeneous and simple. If this is true of the originating body, why should it not be true of the body receiving and transmitting the vibrations? Why is it necessary to assume the existence of three separate fibres in the retina whose office it is to receive the vibrations, when the body giving rise to these vibrations is simple, and with its molecules so arranged that they can vibrate at one and the same time in the different phases corresponding to the different wave-lengths representing the various colors. This it seems to me, is a death-blow to the sole objection advanced against the adaptation of Newton's views to the undulatory theory."

Again, if a fibre is attuned in harmony with waves of a certain length it is physically impossible to make it vibrate to waves of other lengths. Now in the Young-Helmholtz theory, yellow has no fibre corresponding to it, being but a combination of red and green. For the perception of this color there must be a vibration of the red fibre and also of the green ; two fibres adapted to phases of vibration different from each other and from yellow. If this is not a *reductio ad absurdum,* I do not know the meaning of the term.

In cases of unilateral "color blindness," the yellow appears the same in both eyes, whereas if it were a compound color it would appear, according to the theory, as red in green blindness, and as green in red blindness. [From reports of several hundred cases we must conclude that yellow and blue blindness are unknown].

Why should we seek for round-about explanations of nature's laws? She ever follows straight paths, though our eyes may not always discern their entrances, for they may be so blocked up by obstructive theories, that they cannot be entered until we remove the obstacles.

Oliver makes a good point when he says: "The tactile apparatus is one form of telegraphic machinery destined to receive the impressions, whilst the visual apparatus is another form of the same machinery for the receipt of the same character of impressions. Each in itself is a simple mechanism not possesing differentiating power, but merely capable of response when properly acted upon. It would be foolish to assert that there may be special divisions of the peripheral tactile nerves, especially adapted for three empirical sensory impressions, cold, warm, hot, and then to make an artificial gross division of caloric into several arbitrary parts, and say that the different varieties of results are the productions of differences in grade, and amount of action on each or all of these fibres, i. e., that the action of fixed stimuli causes additions or subtractions in unknown degrees upon the organisms of elective power. Yet, here is Young's theory applied to the sense of touch.

Then again, I say that the retina is simply a receptive screen, the flattened end of the optic nerve, having about as much to do with the reception of color as the transmitting diaphragm of the telephone has with the formation of the aërial vibrations by the receiver at the other end of the circuit. We might draw a nearer analogy in the case of the ear drum, a simple membrane, which takes up and carries to the chain of small bones an infinite number of aërial vibrations at one and the same time. It is not even admitted by our latest authorities that the organ of Corti is the final differentiating organ. Even if it were, three fibres are not called upon to vibrate for thousands of tones. By Young's theory an explanation of color blindness has been worked out in an arduous and complex manner with many exceptions. Holmgren and other followers of Young-Helmholtz claim that they are not only able to detect abnormal color perception, but to make a differential diagnosis by this theory, referring to one of the three kinds of "blindness." How does this hold in practice? We have a patient who does not distinguish the reds and greens. Now all the spaces in the spectrum occupied by the colors which the normal eye perceives should be referred, according to the theory, to the third color, i. e., violet. Does he always do this? I answer most emphatically, No! The only distinction between tints falling under the heads of the confusing colors is that of intensity. As colors of the same character differ in intensity, the mistakes arising are likely to be very numerous.

I quote the following from Burnett:

"In comparing the results of these examinations, made by men of recognized ability and capacity for the work, and conducted solely with the view of arriving at the truth, with the phenomena which the Young-Helmholtz theory demands, it will be seen at once that they are far from harmonizing. An individual who is red-blind by one method of examination is pronounced green-blind by another. There is shortening of the red end of the spectrum in the supposed green-blind. There is no gray or neutral line (*n*) in cases where it ought

to be found, and when present, is often situated where it should not be. There seems to be but seldom any loss in brilliancy of the spectrum as a whole, and the brightest part is nearly always found in the yellow, as in the normal eye, and there is no sort of regularity in the manner in which the lost colors are matched. The only two colors about which mistakes are not made are yellow and blue; all other colors are liable to confusion, and in the most unexpected and heterogeneous manner.

The failure of Hering's theory to account consistently for the phenomena of color-blindness (so-called) is equally obvious. In the ordinary form of abnormal color-perception, there is an inability to properly distinguish shades of red and green. It cannot be denied that these colors are *seen*, and that they are distinguished as *colors*, though not in the same manner as in the normal eye, but *never* as simply black or white. Moreover, when the spectrum is looked at, with few exceptions, these colors are as intense as to the normal eye. How then can Hering's theory explain the phenomena? Red and green make an impression—and an impression as strong, so far as we are capable of judging, as these colors do in a properly perceiving eye. It is impossible, therefore, to suppose that a substance capable of being acted on by red and green waves is *lacking*. It can only be supposed, under these circumstances, that in the absence of the red-green substance, the yellow-blue substance acts vicariously, and in addition to its own colors, receives also those peculiar to the red-green substance—a fact which strikes at once at the foundation of the theory, and renders it totally inefficient, not to say absurd.

It will be seen, too, that both these theories make the cause of congenital abnormal perception of colors to be resident in the retina. This arises, in part at least, from the fact that they have made the retina a differentiating instead of a receptive and conducting apparatus. Each fibre or chemical substance is supposed to answer to all the primary color vibrations, and to be more easily and readily affected by some than others, and by those, too, which do not bear any relation to each other that is required by the rules of harmony.

But little attention has been given in the discussions of color-blindness to the part played by the brain in either normal or abnormal color-perception. The fact that *we see with the mind and not with the eye*, seems to have been entirely ignored by the partisans in their zeal for one or the other theory. It has been sought to explain all the phenomena of color-perception, normal as well as abnormal, by means of a normal or abnormal state of the retina, although all must know that *no impression can be converted into a sensation except it reach the brain and be* properly acted upon by the organ which presides over the function of vision.

The last remark of Burnett's is greatly emphasized by another fact of physics concerning vision. Is not an image thrown upon the retina upside down, and do we not see things in the proper position without standing on our heads? We explain this by stating that vision is greatly an educated sense. The perception of form, color and light is not due to the eye alone; all the other senses add some mental factors. As images are not seen in the eye but are referred to a position in space, the child's brain grdually learns to associate the image of the top or bottom of an object with the impressions conveyed by its other senses.

Vision in the adult is greatly modified by illusions; the mind in many instances overrules the impressions conveyed to the brain, substituting memory. A clever draughtsman can indicate a face by a few rough touches, which will be immediately transferred in the spectator's mind to a portrait.[1] The reason for this is that his mind is so familiarized, through recurring experience, with the object, that it is ready to construct the requisite mental image at the slightest external suggestion. All optical illusions can be explained in this manner. We are comparatively inattentive to color which varies with distance, atmospheric changes and illumination. Thus the color of a field of grass, perhaps miles away, is designated green, though in reality it is grayish.

[1]This would simply remain a mass of lines to an uncivilized man who was unaccustomed to the delineation of objects.

How can we explain the effect of contrast by Young's theory? I mean contrast of areas where there is not a true mixture of colored light. Is this not best explained by saying that it is a psychic act? Hering stands upon the same ground that we do, when he agrees to the psychical nature of simultaneous contrast. The same objections may be raised to the theory of Prof. Hering, besides numerous others. The simple colors are not complementary; for instance, the complementary of "R" is not "G" but bluish-green, and there is no reason to suppose that they are antagonistic. White is not the result of subtraction but of addition, as the white formed by the addition of any colors is equal the sum of their intensities, and not the difference. White is not a direct independent sensation, but the sum of all appreciable impressions. Has any other sense been proved to be due to a chemical activity? It is true that Boll and Kühne succeeded in fixing an optogram upon the retina of a rabbit, but as the macula contains no rhodopsin (Boll's purple) it is considered that vision is not explainable by the formation of optograms on the retina. (By the way, photoprints can be taken on any structure of the human body, by direct sunlight, for instance, sunburn or tanning. The subject is exactly where it stood before the discovery of the visual purple. Many of Hering's statements were, I think, rendered impossible, long before his theory came into existence, by experiments in support of Young's theory.)

Now as to the theory of Burnett: I have already shown that the molecules of the luminous body giving white light must vibrate to as many colors as there are in white, and that it is absurd to fix a definite number (3) of bodies in the retina vibrating for more than one color at one time. Why do Young and his followers take the trouble to give a series of organic elements a coarse unnatural division of fibre, in an effort to harmonize them with an arbitrary and unscientific naming of visible colors, when the difference in result depends upon a difference in cause, acting upon an ever ready material. A difference in the character of the natural impressions affecting

one and the same element to a greater or less degree, produces an exact and equivalent answer. If a simple and homogeneous structure like the wire of a telegraphic instrument can transmit more than one message at the same time, why is it not true of each filament of the optic nerve?

We gained some points, I think, when we showed the utter want of support that the Young and Hering theories have from analogy. The phenomena of crossed associations between the senses, among those of colored audition, are undoubtedly psychic. In this there are certain notes, whose perception is associated with the sensation of certain colors. From experiments (some of which I have done myself upon musically gifted persons), there are found to be two kinds, "Photopsie," or simple luminous impressions following sonorous stimuli, and "Chromopsie" or colored visual sensations of which there are many forms. The sense of sight is assisted by the sense of hearing, for barely legible print may often be read when accompanied by a sound. Colors may be recognized at a distance where they were not before perceptible. Colors formerly not visible may be brought into the sensory field. These photisms or sound colors may be produced by experiments; in one, the subject looks at a gray disc of paper upon a white background while the sound is made. The photisms may be caused in consequence of sonorous stimulation by a singing voice only, or by ordinary speech, pronouncing the consonants or vowels, or by instrumental notes as by a tuning fork.

Conversely the sense of audition is reinforced by the sense of sight. The ticking of a watch is made more intense by the sight of blue and green, less by blue and yellow. Sound has its intensity decreased when the eyes are closed. The effect of an impression on one eye influences the sound in the ear on the same side more decidedly than in the other. Excitation of other special sense organs not only affects their own brain centers, but also transmits some vibrations to the other centres. Cases of colored smell and colored taste have been recorded. Perceptible emotions, as joy, sorrow and violent

impulses cause, in some cases, sensations of color. Conversely the sight of certain colors gives rise to peculiar sensations of smell, taste, or certain pyschical conditions. These experiments remind us of persons deaf from disease of the middle ear, who hear better in a noise.

Those persons in whom this phenomena can be produced are only marked examples of a physiological reaction of one sense upon another. For instance, some blind persons see these sound colors after the report of a cannon.

The same or analogous physiological conditions can be provoked, as we have shown, by excitation of different centers, showing that the brain centers are acted upon by the same force. We consider this to be simply *molecular vibration.* All sensation is the result of this force, the different senses are but appreciations of various degrees and characters of these vibrations.

If in a given individual the effects of an excitation of the nerves of special sense were absolutely equivalent, the corresponding sensations would be confounded. These phenomena are illustrations of the great principle or law underlying all natural action—that of the "Correlation of Forces."

They are due to a simultaneous action of external stimuli upon one or more nerve centres, the molecular vibration being propagated from one brain center to another by reason of contiguity, or by anastomoses of nerve fibres. Any disturbance of a special sense gives rise to its peculiar perception. That these phenomena take place entirely in the brain itself, the special sense organs having no action, cannot be denied.

The sense of sight is but a very highly developed sense of temperature. The retinal mechanism simply effects a pro rata reduction of the highly delicate and infinitely divided kinetic energies of the ether wave stimuli into such relatively finite quantities as can alone affect nerve force. It is a translator from the language of the imponderable to the known of neural vibrations. It also transfers these degrees of stimulation to the nerve fibres which convey them to the cerebral color and light producer. This process of reduction and transfer is

through the medium of molecular activities aroused in the retinal receptive organ by the stimulus and perceived by the end organ only according to the height and degree of the aroused molecular activity.

Some facts from biology and embryology claim our attention. The brain and skin are both differentiations of the epiblast. The eyes are essentially dermal structures, being nothing more than a special further development of a nerve and a spot of skin; the retina being the nerve, and the cornea, sclerotic, etc., the skin. In some animals without eyes, as in the medusæ, certain spots upon the skin of some parts are susceptible to light of any kind. A still higher development is found in the pineal eye of some of the extinct vertebrata, which was covered by a translucent skin, being only susceptible to light and having no true vision. These examples simply show an increase in delicacy of the organ and a specialization of certain parts; the grosser waves of ether (i. e., heat) affecting it less and less, and the finer (i. e., light) more and more.

Mr. Gladstone advanced an idea (evolved from his study of Homer and the Vedas), in which he was upheld by a distinguished German scholar, Dr. Hugo Magnus, that the sense of color is not an original endowment of the human race, but that about 3,000 years ago the Semitic and Aryan tribes were incapable of distinguishing between red and blue, green and yellow. Also that white light is the only kind perceived by the inferior order of animals. This view is incorrect. It is not the paucity of the color impressions in uncivilized races that gives rise to this conception, but the poverty of the language to describe them. Mr. Grant Allen, in his examination of the eyes of various uncivilized tribes, found the color sense perfect. White light is the purest we know of, and is the nearest approach to colorless light, which is the complete synthesis of all vibrations. The more numerous the vibrations, the purer or less colored the light, and the less visible it is. Pure light is invisible, only impure or colored light is seen and therefore visual perception is of color and not of light. The

simplest form of visual apparatus has probably but few differentiations of impure light at its command. As the higher forms of life are examined the number of received impressions increases. Then we all know that flowers are variously colored for the attraction of insects, etc. Many forms of life are colored as a protection, simulating their surroundings.

An abnormal state of any part of the nervous apparatus, the retina, optic nerve or different parts of the cerebral center will cause some alteration in the normal sensation. As the retina is merely a disc-like expansion of the optic nerve, we may divide cases of abnormal color perception into central and peripheral. For example, in hypnotism and the psychic blindness of aphasia, the abnormal color perception is clearly cerebral (or central). Also in the effects of certain drugs, as the yellow vision from Santonin and in alcoholism. Of the peripheral forms we have optic atrophy (where the contraction of the color field is entirely out of proportion with that of white), and cases resulting from inflammation of the retina, etc. These depend either upon the inability of the retina to take up, or of the optic nerve to carry certain vibrations. To the peripheral class belong many of the cases where shortening of the spectrum occurs. A peculiar aberration is seen in psychic blindness, where the optical memory areas are affected, and form and color are seen, but make an unfamiliar impression.

It is supposed that the normal retina and nerve respond to some ether waves more easily than to others. They seem to be unaffected by the ultra-violet and ultra-red rays of the spectrum. Is not this carried still further in "color-blindness," and other colors modified or excluded from alterations in their anatomical or molecular structure? "All we know in regard to differentiation of impressions points to the brain as the place where the final process leading to judgment takes place, and it cannot be denied, except in rare cases where there is shortening of the spectrum, that the mistakes of the 'color-blind,' so called, are "errors of judgment." Now, where two colors are confused it is not necessary that they make precisely the same impression on the central cells; but, that on

account of the individual's "obtunded color-sensibility," they are so nearly alike that he is apt to confound them. The vibrations fail to excite the cerebral molecules in a full degree. We frequently find individuals who are unable to differentiate the finer shades of the same color. This is called a "diminished chromatic sense." Holmgren was unable to make any distinct lines of demarcation between this and what he called "color-blindness." It is utterly impossible to account satisfactorily for such phenomena on any other basis than that of defective judgment. We therefore look upon "color-blindness" as an exaggerated condition of "diminished chromatic sense." Observers are agreed that the name "color-blindness" is a misnomer, and that very few cases are really blind to color. "It is absurd to believe that because shades of red and green cannot be differentiated, that the person is really blind to either (*i. e.*, that the patient cannot see them at all). He does see them, and sees them as colors just the same as he sees yellow or blue, but cannot separate the impressions made by the one from those made by the other." We would designate all these cases under the specific heading dyschromatopsia, to take the place of "achromatopsia, which signifies *no* color vision.

Observers have studied to some extent the subject of residual sensations, or after images, of white light; but so far as I can ascertain, they have only experimented upon themselves. I have done this myself many times, but have also experimented upon ten artists and draughtsmen who were competent to make quick judgment of the fast fleeting colors.

TABLES

Showing Character of the Residual Sensations of White Light From Experiments Upon Ten Artists.

TABLE I.,

Showing Three Typical Cases With the Duration of Each Impression.

—1—

V. M.

Typical Spectrum.

Duration. Min.	Duration. Sec	Colors.
		Ten sec. before image appears.
	10—20	Carmine.
	—30	Carmine rim, yellowish green center.
	—40	Pale pea green.
	—45	Crimson.
	—55	No image.
—1		Yellowish - green "ghost."
—1	10	Scarlet.
—1	15	No image.
—1	30	Magenta red.
—1	40	Prussian blue.
—1	52	No image.
—2	7	Prussian green rim, Prussian blue center.
—2	12	No image.
—2	22	Prussian green rim, Prussian blue center.
—2	32	No image.
—2	47	Bluish Payne's gray.
—3	2	Payne's gray rim, bluish center.
—3	17	Dirty Prussian blue.
—3	37	Fading away as a neutral tint ill defined.

Images stationery; of same relative size; gradually diminishing in intensity.

—2—

H. R.

Warm Colors.

Duration. Min.	Duration. Sec.	Colors.
		Five sec. before image appears.
	5—15	Carmine.
	—30	Orange.
	—40	No image.
	—45	Sepia.
	—55	Greenish yellow.
—1	15	Emerald green.
—1	28	Prussian green.
—1	35	No image.
—1	40	Yellowish - green "ghost."
—1	55	Fading away, as very light yellowish green.

Images usually at bottom and rise to top of visual field; they gradually increase in size to the *emerald green* and then diminish both in size and intensity.

—3—

J. H. K.

Cold Colors.

Duration. Min.	Duration. Sec.	Colors.
		Sixty sec. before image appears.
—1 —1	10	Yellowish green
—1	20	Prussian green.
—1	30	Light Prussian blue.
—1	40	Dark Prussian blue.
—1	50	Bluish purple.
—2	10	Indigo.
—2	30	Neutral tint.
—2	45	Black.
—3	5	Fading away as a shadowy neutral tint.

Images usually appear at top and sink diagonally downward to bottom of visual field; they gradually diminish in size and intensity. Sizes, colors and directions can be altered at will.

TABLE II.

TWENTY SECONDS EXPOSURE.

—4—

D. W. G.

1. Greenish-yellow center; red rim.
2. Yellow.
3. Yellow center; carmine rim.
4. Pink.
5. Carmine.
6. Carmine center; purple rim.
7. Reddish purple.
8. Purple center; Prussian blue rim.
9. Indigo center; light blue rim.
10. Carmine ("ghost.")
11. Indigo.
12. Neutral tint.

Images float about the field. Colors merge.

—5—

J. B. T.

1. Greenish-yellow.
2. Yellow.
3. Orange.
4. Light red.
5. Carmine.
6. Light blue.
7. Reddish purple.
8. Carmine ("ghost.")
9. Prussian blue.
10. Pur le ("ghost.")
11. Prussian blue.
12. Indigo.
13. Light blue.
14. Payne's gray.

Images disappear between colors floating upward.

—6—

G. S.

1. Yellow.
2. Carmine.
3. Purple.
4. Prussian blue.
5. Prussian green.
6. Light green.
7. Prussian green ("ghost.")
8. Prussian blue ("ghost.")
9. Indigo.

Images disappear between colors gradually diminishing in size and intensity.

—7—

H. G.

1. Red center; bluish rim.
2. Orange.
3. Olive green.
4. Prussian green.
5. Olive green ("ghost.")
6. Prussian green.
7. Light blue.
8. Prussian blue.
9. Light blue ("ghost")
10. Prussian blue.
11. Payne's gray.

Images gradually diminish in size and intensity.

—8—

H. S.

1. Prussian blue.
2. French blue.
3. Indigo.
4. Neutral tint.

Sizes, colors and directions can be altered at will.

—9—

C. M.

1. Yellowish-green.
2. Orange.
3. Orange center; red rim,
4. Prussian blue.
5. Purple.
6. Dark purple.
7. Mauve (shadowy).

Images diminish in size to the Prussian blue, and then increase; colors gradually diminish in size and intensity.

—10—

H. V. W.

1. Mauve.
2. Purple.
3. Prussian blue.
4. Purple ("ghost.")
5. Prussian blue.
6. Indigo.
7. French blue upper half; indigo lower half.
8. Light indigo.
9. Payne's gray.
10. Neutral tint.

Images diminish in size and intensity dropping diagonally downward; sizes, colors and directions can be altered at will.

A number of methods have been tried, but the following is probably the best: A white piece of paper was placed upon a dull black back-ground and looked at in the sunlight for a certain length of time. (Fig. 4.) Then the eyes were gently

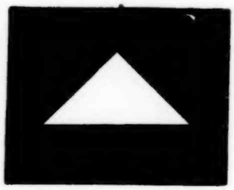

FIG. 4.

closed and covered with the hands so as to exclude all light. Then a vivid image appeared, the color of which was named and committed to paper by a second person. This image changed to another color, and then to others, finally disappearing.

The personal equation of each observer is, of course, of some consequence, as some persons appreciate colors more easily than do others, but I find that after images, as a rule, follow the colors of the spectrum, beginning at the upper end and continuing to the lower. The impressions may be modified to a considerable extent by the will. For instance, one of my subjects, after practice with these colors, always saw a full spectrum immediately upon the closure of the lids. In some cases the image may be altered in size, or it may be made to move about the field by a process of expectation. Also the image may be excluded or the colors may be modified at will by the subject. There are times when the image does not gradually merge into the next but disappears suddenly, appearing in a different color. Pressure upon the globe of the eye influences the color and appearance of these images. This is due to the fact that any irritation of the nerve or retina gives rise to a sensation of light. Sometimes a color is entirely omitted (the image not being appreciated at the time it

ought to appear). Sometimes only the first part of the spectrum is seen, and sometimes only the last part. In my own experience fully a minute elapses before I see any image[1]. On some days more colors are distinguished or the list is lengthened by the addition of one or more colors at either end. When a color, for instance, purple, which is usually thought of as being compound, is viewed out of order the sensation is psychical, being due to a changing from the red to the blue, confusing the two impressions. When other simple colors appear out of order they have been seen before and are "ghosts" or revivals of preceding impressions.

This is proved by making a half dozen exposures closely following each other; when the eyes are closed no very distinct views are obtained and colors follow without definite order When the eyes[2] are suddenly turned the image gradually gets in line with the visual axis, this is due to the fact that the mind projects all objects into space, and as the cells in the brain corresponding to the maculæ were primarily provoked, the mind considers that the image seen should be in the line of the visual axis.

The brain is the workshop of the soul and indeed its entire world is constricted within the narrow limits of the cranium The ego is cognizant of nothing that goes on outside of the brain; every action in the body (which can be appreciated) is telegraphed to the brain, and there makes some change which is referred to a position in space, as Epicharmus, the old Greek poet says, "T'is mind alone that sees and hears, all things besides are deaf and blind."

In all action there is a disintegration of tissue, and it is reasonable to suppose that when the central cells are irritated, there is some change in the molecular relation of their constituents. This change may be evanescent, lasting but for a fraction of a second, until the reparative process is complete. If the irritation is kept up for a length of time, or repeated, or

[1]In such cases the first part of the spectrum is seldom seen.

[2]Or eye experimented upon.

if it is of great intensity, the impression or change is more permanent. Finally, the impression may be of such a nature as to be carried to the memory cells of the brain, where it may make either transitory or permanent changes. Another kind of residual sensation is observed after certain operations on the eye, when the patient sees everything colored violet or reddish. This continues from fifteen minutes to one hour, and is due to an after image of some bright object.

These residual sensations are simply memories, the successions of colors being due to disintegration of the white light impressions in the brain cells themselves. The fact that the action is ever decreasing in intensity is due to the gradually lessening impression, some waves irritating for a longer time than others, and to the reparative processes going on in the recipient tissue. I have tried these experiments in many ways, and with other than white light. On every side they uphold the statement that differentiation of color is effected in the brain and not in the retina.

Burnett divides vision into quantitative and qualitative. The first relating to the size of the image, *i. e.*, the number and relationship of the retinal elements (and the corresponding elements in the brain) that are acted upon. (At a distance of less than 20 feet another factor comes into play, a sort of muscular sense developed by education, *i. e.*, the accommodation and convergence of the eyes.) Qualitative vision is the color sense proper, resulting from a discrimination between changes experienced in the brain cells between ether waves of different lengths and rates of motion.

Are there then separate centers in the brain for light, form and color perception, or for separate the colors? I see no necessity for the assumption.

Burnett says: "I would suppose the cerebral molecules or atoms to be capable of vibrating in the same phases as their corresponding molecules in the retina, or going farther back still, in the substance of the luminous body itself. Of course, under this hypothesis it is not demanded that there be a special phase of vibration for every distinctly-perceptible color

and shade. It is still possible to divide colors into "primary" and "combination." As for myself I should regard as "primary" all those colors which are clearly distinguished as such in the full solar spectrum. All others I would regard as "combination colors." "

White light is more intense than colored, since it is the sum of all the ethereal vibrations. The whole must include all of its parts. All white light sensations can be resolved into their constituent elements of color sensations. Therefore, there is no necessity for separate color centers, nor is there need for a separate form center, if we accept the explanation given of quantitative vision.

As stated, this paper is mainly a review, bringing together the more important theories advanced from time to time concerning color perception, and an attempt to record a few thoughts in support of, what the writer believes to be, the rational view of the subject.

The way for any theory to become a recognized law is for each observer to contribute his mite, however meagre, towards its establishment.

BIBLIOGRAPHY.

"Theories of Color Perception," Swan M. Burnett, M.D.—Am. Journ. Med. Sci., July, 1884.

"Are There Separate Centers for Light, Form and Color Perception?" Swan M. Burnett, M.D.—Arch. of Med. Vol. xii, No. 2, Oct., 1884.

"On Heat, Considered as the Retinal Intermediate of Light and Color Sensation," L. Webster Fox, M.D., and Geo. A. Gould, A.B.—Am. Journ. Ophth., July, 1886.

"A Correlation Theory of Color Perception," Chas. A. Oliver, A.M., M.D.—Am. Journ. Med. Sci., Jan., 1885.

"Remarks on Colors and Color-Blindness," F. C. Donders, M.D., LL.D., F.R.S. —British Med. Journ., Nov. 13, 1880.

"Colored Vision and Equivalence of Sensory Vibrations," Ch. Feré.—Journ des Soc. Sc., Nov. 21, 1888.

"Ueber den Einfluss einer Sinneserregung auf die übrigen Sinnesempfindungen," Victor Urbantschitsch.—Pflüger's Archiv f. d. ges. Physiologie, xlii 3-4, 1888.

Prof. Hering.—Journ. Psycholog., May, 1888.

"Diseases of the Nervous System," Gowers, 1888.

"Ueber die Ursachen der Erythropsie," Dobowlowsky.—Archiv. für Oph., Vol. 33, p. 213.

"On the Development of the Color Sense," Montague Lubbock.—The Fortnightly Review, April, 1882.

"Duration of Color Impressions Upon the Retina," Edward Nichols, Ph.D.—Am. Journ. Scien., Vol. xxviii, Oct., 1884.

"Die Seelenblindheit als Herderscheinung und ihre Berziehungen zur Homonymen Hemianopsie and zur Agraphie," Dr. Hermann Wilbrand.—Wiesbaden, 1887, p. 192.

"The Color Sense; Its Origin and Development," an essay in comparative psychology, Grant Allen, B. A., New York, 1879.

"Physological Optics," Helmholtz.

"The History of Young's Discovery of His Theory of Color," Alfred M. Mayer.—Am. Journ. Sci. and Arts, third series.

"Diseases of the Ear," Samuel Sexton, M.D., Philadelphia, 1888.

"A Treatise on the Eye, the Manner and Phenomena of Vision," Wm. Potterfield, Edinburgh, 1759.

"A Treatise on the Senses, Instincts and Intelligence of Animals," Sir John Lubbock.—International Scientific series, 1888.

"Illusions," James Sully.—International Scientific Series, 1881.

"Modern Chromatics," Ogden N. Rood.—International Scientific Series, 1880.

OCULAR HEADACHE.

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As usual, concerning any topic under discussion by myself, I shall, at the outset, try to show that my ideas, upon it, are in accord with those of some other men who are generally regarded, by *connoisseurs*, as having a right to speak of it authoritatively.

Dr. Wm. Thomson[1] reports that: "Of 1,000 cases of refractive errors, Bickerton found that in 277 headache was a distinct symptom." Dr. Thomson, in the same place, speaks of an article of my own,[2] as one of "other praiseworthy efforts to popularize the subject." This is cited only to indicate that Dr. Thomson considers such efforts "praiseworthy." Seventeen other authors are quoted, in Dr. Thomson's work, (on the page cited and the one succeeding it) as having found eye-strain to be a source of headache.

In Landolt's work on refraction and accommodation, the author[3] says: "The myope often experiences at the bottom of the orbit, or even in the entire forehead, a sensation of pressure which may become a genuine cephalalgia. The pain becomes more and more intense and more and more frequent, sometimes even constant, and often takes on the character of a neuralgia. Indeed it is not rare to see these phenomena, as also asthenopia generally, mistaken for neuralgias dependent

[1]Thomson. Sajous' Annual of the Universal Medical Sciences, 1888, Vol. III, p. 152.

[2]Culver. Albany Medical Annals, Vol. VIII, p. 137.

[3]Landolt. The Refraction and Accommodation of the Eye, p. 456.

upon some affection of the nervous system, and treated accordingly, without, of course, any success, and to the detriment of the general health."

Under the heading of Hyperopia, Dr. Landolt[1] writes, in the same work: "Others * * * are early tormented by symptoms of asthenopia, provoked by the excessive working of their accommodative muscles. * * * A sensation of heaviness, which may pass into real pain, invades the eyes and forehead. This cephalalgia may take on the form of a genuine migraine and render impossible, not only all work, but even the fixation of the most distant object."

Let me say, parenthetically, that I do not suppose I am communicating *news*, herein, to educated oculists. The subject has so progressively excited my interest, of late years, that I deem its discussion a *potential* source of benefit to any reader, whether of the laity or of my colleagues.

In his work on "Functional Nervous Diseases," Dr. Stevens[2] devotes twenty-five pages, directly, to the consideration of headaches produced by ocular anomalies.

In the transactions of the Pennsylvania State Medical Society, for 1886, Dr. Edward Jackson[3] published a valuable article on "The Relation of Eye-strain to Headache." The first words of it are: "Headache due to eye-strain is very common;" and the rest of the article abundantly demonstrates the truth of that initial statement.

In the New York *Med. Rec.* (an issue of September, '76, of which I cannot give the exact date, only a reprint being now at hand) Dr. Stevens[4] said that: "In more than one hundred cases of severe, recurring headaches, including several which were clearly of the form called migraine, refractive anomolies have been found without exception."

In an article entitled "Oculo-Neural Reflex Irritation," read

[1]Landolt. The Refraction and Accommodation of the Eye, p. 370.

[2]Stevens. Functional Nervous Diseases, p. 35-60.

[3]Jackson. Transactions of Pennsylvania State Medical Society, 1886.

[4]Stevens. New York Medical Record, September, 1876.

before the International Medical Congress, in London, England, August, 1881, the same author[1] said: "The results of observation in several hundred carefully recorded cases of such diseases as neuralgia, chorea, insomnia, *headaches* (Culver's italics), and even epilepsy have fully confirmed the opinions long since expressed by me that difficulties in performing the function of sight are among the prolific sources of nervous diseases."

In the New York *Med. Journ.* for April 16, 1887, may be read what Dr. Ambrose L. Ranney said in a meeting of the New York Neurological Society (March 1, 1887), viz.: "I do not pretend to speak as an oculist, but as a neurologist: * * * * I have never yet encountered a case of typical migraine in which some form of eye-defect did not exist."

In the first fasciculus for 1888 of the *Annali di Ottalmologia*, Dr. Rampoldi[2] reported a case of hemicrania, which had been under his observation and treatment.

Dr. Ambrose L. Ranney[3] has written: "I believe that the symptoms of sick-headache are of a reflex character, to a large extent, and are due, primarily, in almost every case, to some optical defect." Again: "I do not think the relationship between eye-strain and attacks of headache or neuralgia can be denied."

Dr. Henry D. Noyes[4] asserts that "not a small percentage of headaches originate in disorders of the ocular muscles."

Dr. C. S. Bull[5] says: "Many cases of obstinate headache, which have resisted all treatment, originate in disorders of the ocular muscles and disappear when these disorders are corrected."

In January, 1885, Dr. G. S. Norton[6] published an article

[1]Stevens. Alienist and Neurologist, January, 1882.

[2]Rampoldi. *Annali di Ottalmologia*, Fasc. I, p. 58.

[3]Ranney. New York Medical Journal, Vol. XLIII, p. 231.

[4]Noyes. Diseases of the Eye, p. 88.

[5]Bull. In Soelberg-Wells, Diseases of the Eye, p. 719, 4th American edition.

[6]Norton. The Hahnemannian Monthly, January, 1885.

on "The Eye as an Agent Causing Headaches and other Nervous Disturbances." Therein, in twenty-eight cases, is shown the connection between the various forms of refraction and headache, or other nervous disturbances.

Before the *Societe Francaise D'Ophtalmologie*, on the 31st of January, 1884, M. Martin,[1] of Bordeaux, sought to demonstrate that, in a vast majority of cases, migraine is dependent on astigmatism. In such demonstration he was supported by Javal;[2] he was opposed by Dianoux, but, as I presume to think, with a statement that was simply false.

Galezowski,[3] in the *Recueil D'Ophtalmologie*, has written concerning ophthalmic migraine and its semeiological value.

De Latourelle[4] reported to the *Societe de Biologie*, in June, 1887, a case of ophthalmic migraine.

Dr. Parinaud,[5] in 1887, wrote concerning ocular cephalalgias. In the article he says: "*C'est dans l'appareil musculaire de l'oeil que reside presque toujours la cause de la cephalalgie.*" "(It is in the muscular apparatus of the eye that the cause of cephalalgia almost always resides.)"

In 1883, Dr. Eperon,[6] who wrote the bibliographical analysis for the *Archives D'Ophtalmologie*, reviewed the thesis of Dr. Raullet,[7] on ophthalmic migraine. Dr. Eperon wrote: "*La migraine ophtalmique, observee par Piorry, a fait dernierement le subjet de travaux interessants de M. Charcot et de son eleve M. Fere.*)" "(Ophthalmic migraine, observed by Piorry, has lately been the subject of interesting work by Charcot and his pupil, Féré.)"

The present writer, Culver, was once a student under Char-

[1]Martin. *Archives D'Ophtalmologie*, Tome IV. p. 170.

[2]Javal. *Loc. cit.*

[3]Galezowski. *Recueil D'Ophtalmologie*, IV, No. 9, p. 536.

[4]De Latourelle (cited by reviewer, Dr. Rolland), *Recueil D'Ophtalmologie*, 1887, p. 622.

[5]Parinaud. *Recueil D'Ophtalmologie*, 1887, p. 663, also vol. III, 1883, p. 467.

[6]Eperon. *Archives D'Ophtalmologie*, 1883, Tome III, p. 537.

[7]Raullet. Th. Doct., Paris, 27 Juin, 1883.

cot, and although it might not be easy to formulate his reasons for holding the opinion, he thinks it a considerable concession on Charcot's part, that there *is* such a thing as ophthalmic migraine.

Féré[1] also reports a case of ophthalmic migraine, followed by death; in another place he discusses the treatment of ophthalmic migraine[2].

Snell[3] has written about "Recurrent Paralysis of the Third Nerve, with Attacks of Migraine."

It seems strange to me that in my study of this subject, I have found so scanty reference by German authors to ocular headache. My former master, Schweigger[4], refers to it, but merely as a part of asthenopia. I am not now pretending to compile a complete bibliography of the topic, but, if my citations seem to ignore German works, the possible inference may be precluded by my saying that I believe it to be a *fact* that ocular anomalies are largely more productive of headache than they are commonly supposed to be; and that Germans have for more than half a century done more than half of the valuable scientific work, bringing forth a knowledge of *facts*, that has been done in the world.

Dr. Stewart[5] gives the history of a case of what I would class with ocular headaches, though the connection is not as direct in the case reported as it often is.

Mr. Brudenell Carter[6] gives the history of a case, which I[7] have already cited, in another article, wherein intense headache had been a prominent symptom, but disappeared when Mr. Carter treated the patient's eyes, merely prescribing con-

[1]Féré. *Revue Mensuelle de Medicine*, III, 4.

[2]Féré. *Progr. Medical*, No. 23, p. 454.

[3]Snell. The Lancet, No. 21. (1885).

[4]Schweigger. *Augenheilkunde*, Vierte Auflage, p. 50.

[5]Stewart. American Journal of Ophthalmology, vol. V, p. 184.

[6]Carter. Eyesight, good and bad, p. 144, and Diseases of the Eye, p. 563.

[7]Culver. Albany Medical Annals, vol. VIII, p. 158.

cave glasses, mainly to establish harmony of accommodation and convergence.

Dr. Swan M. Burnett[1] considers this subject of ocular headache, briefly, and quotes Dr. S. Weir Mitchell as having called attention to it in 1876.

I now propose to cite ten cases of headache that has succumbed to my own ocular treatment:

Case I. Mr. W. S. S., æt. 52, consulted me Feb. 9th, 1888, at the suggestion of Dr. J. D. Featherstonhaugh. Eighteen years earlier had had an iridectomy performed on left eye. Three years ago, another of my local colleagues prescribed glasses for near-work. The left cornea is of so irregular curvature that vision in that eye amounts to only $^{15}/_{cc}$, which no glass improves. He said that the glasses he had had were each sph.$+^{1}/_{18}$; but I did not have a chance to see them. Vision of right eye was $<^{20}/_{xxx}$ but, with a Cyl.—1.75 D. axis 15°, it became equal to $^{20}/_{xx}$.

My prescription was simply a Sph.+2.00 D. $\bigcirc$ Cyl.—1.75 D., axis 15°, for the right eye, and a plane glass for the left eye, these being for use when doing near work. The patient is paymaster in the Harmony Mills and has much clerical work to perform. This prescription was dated the 8th of Feb. 1888. Result: On the 18th day of the same month he wrote: "I cannot spare the glasses, which suit me to a T." May 5, 1889, he orally communicated with me, personally, to this effect: "I used to be crazy with headache all the time; I have never had a headache since you sent me the hook-bowed spectacles."

Case II. Miss M. F., a schoolgirl, æt. 13, consulted me the 19th of March, 1887, at the suggestion of Dr. Franklin Townsend. Dr. Townsend had previously told me that he prognosed convergent strabismus, in that case, unless her eyes soon received appropriate treatment. Her head had ached a great deal. I found the eyes to be, on inspection, perfectly normal in all respects. There was hyperalgesia at *each* supraorbital

[1]Burnett. Treatise on Astigmatism, pp. 151-152.

notch, and each infraorbital *foramen*. There being present no manifest anomaly, but latent hyperopia and latent convergent strabismus, I thoroughly atropinized both eyes; then, during complete mydriasis, the right eye, without a glass, had $V. < {}^{20}/_{c}$; with a Sph.+1.75 D., it had $V. = {}^{20}/_{xx}$; at the same time, without a glass, the vision of the left eye was $V. = {}^{10}/_{cc}$; with a Sph. +4.00 D. $\supset$ Cyl.+0.50 D., ax. 90°, $V. = {}^{20}/_{xx}$. I made some allowance for the strength of glasses because of her youth, and left about a dioptry of her general hyperopia uncorrected by the glasses I prescribed. By the way, I now doubt the wisdom of making such allowance. Result: Just two months after her consultation with me, and while I was out of the city, Dr. Thomas Featherstonhaugh, then my associate in practice, saw the patient. I append his record. "Child, previous to visits here, used to have most intense headaches, accompanied by vomiting. She was treated for biliousness, etc., but got no relief until glasses were prescribed. She now has no headaches, and has not vomited since her first call here."

Case III. Miss I. T., lady æt. 20, had had vertigo since the spring of 1887. Had no symptoms peculiar to the eyes, but Dr. A. Van Derveer advised her to consult an oculist. She consulted me November 16, 1887. Her subjective history included the apparent vertical elongation of distant lights, great nervousness, and headache induced by near work. On the 19th of November, 1887, I prescribed for the right eye, Sph.+0.75 D., and for the left eye, Sph.+0.75 D., $\supset$ Cyl.+0.50 D., axis 180°, these lenses mounted as eye glasses. By von Graefe's test, on the 17th of April, '88, there was endophoria for five metres, that was corrected by 3° of old-fashioned angle-of-opening prism, and whose maximum correction was 5° of the same sort of prism. On the 8th of May, '88, I replaced the Sph.+0.75 D., right lens with a S.+0.75 D. $\supset$ prism 2° (angle of opening) apex toward nose. Result: On the 24th of January, '88, I had a report that my treatment had relieved the former headaches. May 8, 1888, the report, as recorded in my case-record, reads: "Hasn't had so much headache since she has had the glasses I prescribed, but has had a *few*

severe attacks." I afterwards learned that at first these glasses were worn by my patient only in a desultory way. Feb. 16, 89: "Patient has no more sick headaches now, but does have left temporal headache." I used orthoptic training of the interni and enjoined more nearly constant use of glasses. Sixth of June, '89: "Patient's sister reports that patient's headaches have quite ceased."

Case IV. Mr. G. P. W., merchant, æt. 52, consulted me the 12th of May, 1885. With his right eye, without a glass, V.=$^{15}/_{xxx}$: Left eye, without a glass, V.=$^{15}/_{xx}$. Either eye with Cyl.+0.75 D., axis 90°, V.=$^{15}/_{xv}$. In this case a rule-of-thumb prescriber had signally failed. Mr. W., after having my prescription filled, compared the resulting glasses carefully with the rule-of-thumb glasses (prescribed, unfortunately, by a colleague). The patient found that his head ached whenever he used the latter glasses, and that it never ached when he used the sphero-cylinders, prescribed by myself, under corresponding circumstances.

Case V. Miss R., æt. 16, schoolgirl, consulted me April 9, '89, to learn if treatment of her eyes would relieve her very annoying headache. I found each eye myopic and prescribed lenses correcting *real* myopia. I did not regard her as a typical victim of ocular headache, and so reported to herself and to her father. But she had worn a sphero-cylinder in front of the right eye, before I saw her. When she consulted me, a simple Sph.—4.00 D., gave V.=$^{20}/_{xx}$; hence I knew that I could somewhat improve upon the circumstances under which her visual act had been performed, and told the patient and her father, that I expected *some* relief to attend her use of my prescription. Result: Five and a half weeks later (May 18, '89,) I received a report that Miss R. had had no headache since she had worn the glasses I prescribed.

Case VI. On February 22, 1889, Miss A. L., æt. 54, consulted me, giving a history of being "somewhat bilious," "very nervous," and having much headache. Without glasses or mydriatic, her right eye had V.<$^{20}/_{xl}$, and her left eye had V.<

$^{20}/_{L}$; with Cyl.+0.75 D., axis 90°; the right eye had V=$^{20}/_{xxx}$; and with Cyi.+1.25 D., axis 90°, the left eye had V.=$^{20}/_{xxx}$; V.=$^{20}/_{xxx}$ was the best vision obtainable for either eye by a glass. I prescribed proper correcting glasses, fôr use during distant-vision, and proper sphero-cylinders for use when doing near-work. Result: Nearly three months later (May 16, '89,) my patient reported, orally and personally, that her headache had not recurred since she had worn the distance-glasses I had prescribed.

Case VII. On the 19th of December, 1885, Mrs. McC. consulted me, giving an account of having suffered much from severe nervous headache. So-called "walking glasses," (each Sph.+1.50 D.,) had been prescribed for her, as well as right Sph.+3.50 D.. and left Sph.+4.00 D., for reading purposes. Without glasses or atropine the right eye had V.<$^{15}/_{LXX}$ and the left eye V.=$^{15}/_{C}$; I found that Sph.+1.50 D. ⊂ C.+1.00 D., axis 180°, gave the right eye V.=$^{15}/_{XV}$+; and that Sph.+1.75 D. ⊂ Cyl.+0.50 D., axis 180° gave the left eye V.=$^{15}/_{XV}$; I prescribed such glasses for distant vision, and near-work sphero-cylinders, of strength to correspond to the requirements made by my patient's natural presbyopia.

Result: On the 22d of May, 1888, Mrs. McC. reported to me that she had been completely relieved from headache and eye trouble, ever since she finished treatment under me, over two years before. (It may be well to add that a course of tonic treatment, conducted by myself, had been undergone by my patient, who would never have gotten the benefit of my optical prescription, had she not fitted herself for it by intelligent persistence, and a course of quinine and strychnia).

Case VIII. On the 27th of Feb., '89, Miss C. M. V. D., æt. 30, a lady whose time is much occupied by sewing, consulted me, giving a history that from the 23d of Feb., '88, she had had headache every day for three weeks; then eyesight, for sewing, was blurred; the headache she described was temporo-frontal, sub-bulbar and bulbar; stomach was somewhat out of order. Either eye, without glasses, had V.=$^{20}/_{XX}$; either eye with Sph. +1.00 D., ⊂ C.+0.50 D., axis 90°, had V.=$^{20}/_{XX}$; koroscopy

having shown me that the least hyperopic meridian (vertical) of each of her eyes had a hyperopia of 1.50 D., I prescribed for each eye, Sph.+1.50 ⊃ Cyl.+0.50 D., axis 90°. A week later, with the spectacles I had prescribed, both eyes, together had V.=$^{20}/_{xx}$; either eye alone, with the glass I had prescribed for it, had V.=$^{20}/_{xx}$.

Result: Just three months after having received my optical prescription, she wrote to me about the glasses, saying: "I have worn them steadily and I think that they have helped me. * * * In sewing or reading I have no trouble." In that letter she made no special mention of her former very troublesome headache. I wrote, asking how *it* had been affected by my prescription. On the 2d of June, '89, she answered me, saying: "* * About my headache—I had nearly forgotten all about it, as I had been free from it for nearly three months. —I also find on taking a day for pleasure, or riding on the cars, I have suffered no headache (since I have had the glasses) and before that I could not ride a very short distance on the cars without suffering for hours with a headache. The day I went to Albany, last winter, I fought headache all day (by taking headache medicine) to drive it off, but it came on at last, but not so severely; but the day I came home, having on the glasses (and I spent about five and a half hours in Pittsfield, so not reaching home till six o'clock at night, leaving home at ten o'clock) I did not have a touch of headache at all."

Case IX. On the 19th of October, 1887, Mr. N. J. G., a theological student, æt. 26 years, consulted me, as he had been advised by my former pastor and friend, Dr. T. G. Darling, to do. He gave a history of severe frontal and temporal headache, and "malaria," the causation of the headache being ascribed by the patient, himself, to "eye work." His headaches and malaria had forced him to leave the theological seminary. When I first saw him there was no mydriasis, and each eye, without a glass, had V.<$^{20}/_{xx}$; the right eye, with a Cyl.+0.50 D., axis 45°, had V.=$^{20}/_{xx}$; and the left eye with a Cyl.+0.50 D., axis 115° had V.=$^{20}/_{xx}$; *experientia* certainly *docet*, and, although I had not, then, the advantage, which I

have since acquired, of using the shadow-test accurately, I had no faith in the really beneficial action of these cylinders with obliquely inclined axis, and so I told Mr. G. No spheric glass was at all accepted by either eye, when I first saw him. Acting on my advice, he permitted me to thoroughly atropinize both eyes; then it was a Sph.+1.25 D., $\bigcirc$ Cyl.+0.50 D., axis 90°, and a stenopaeic aperture, of three millimetres diameter, which brought his vision up from its natural V.$<{}^{20}/_{LXX}$ to ${}^{20}/_{XX}$; and it was a Sph.+2.00 D. $\bigcirc$ Cyl.+0.50 D., axis 90°, and the same kind of a stenopaeic disc that did the same thing for the left eye, giving it normal vision. I prescribed spectacles corresponding to the result of my examination.

Result: On the 3d of November, 1887, Dr. Darling wrote to me, saying: "Yesterday I heard from Mr. G., who was very hopeful, and the cheerfulness was evidently giving him a stronger grip on life and work."

On the 25th of November, '87, Mr. G. wrote me, saying: "It is now one month since I began to wear the glasses. I experimented with them this morning by going without them for a couple of hours, but am glad to get them on. They are now no trouble to me, and in every case I can see clearly with them. My head does not get weary now when I work."

Case X. Miss S. E. B. consulted me June 10, 1886. She gave a history of having had, ten years before, what I think, from her description, must have been phlyctænular keratitis, and for which Dr. Robertson had successfully treated her, with the classical remedies, calomel, cod-liver oil, etc. When she consulted me she had lately had headaches which the usual remedies had failed to relieve. She ascribed the headaches, herself, to the use of her eyes. Either eye, without a glass, had V.$<{}^{20}/_{XXX}$; with Cyl.+0.75 D., axis 90°, the right eye had V.$={}^{20}/_{XX}$; with Cyl.+1.00 D., axis 55°, the left eye had V.$=$ ${}^{20}/_{XX}$. I prescribed such glasses, only, her age being less than that at which presbyopia is supposed, by most of us, to become manifest.

Result: A little more than four months later (Oct. 18, 1886) Miss B. reported herself perfectly well, and that she had

found her spectacles indispensable. I have seen the patient several times since then, and the report continues as satisfactory as it then was.

My present opinion is that ocular headache is a topic worthy of further discussion, and my present purpose is to discuss it further in the future.